WINTER ICE COVER IN THE GREAT LAKES

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1. ABSTRACT

This report is the result of a year's part-time study of the problems of the distribution of winter ice in the Great Lakes. The original statement of the project ran as follows:

> "No systematic study of the life history and geographic distribution of winter ice cover on the Great Lakes has ever been undertaken, though such a study is the first step in any attempt to devise a means for artificially lengthening the navigation season. It is therefore proposed that a study be initiated in which the known ice data on the three upper lakes is assembled and evaluated as a first step towards a more extensive field study in which new techniques developed over the last decade could be applied." (Zumberge, 1961)

When the writer came to Michigan the feasibility of the proposed study was considered in detail, and a survey of the types and content of known ice data was made. It was found that the analysis of this material would not substantially increase knowledge of ice distribution on the three upper lakes. Further work along these lines was, therefore, abandoned, and attention was turned to the second phase of the project, the problem of organizing a more extensive field study.

2. PRESENT KNOWLEDGE OF ICE DISTRIBUTION IN THE GREAT LAKES

In view of the importance of the Great Lakes as a commercial artery, there is remarkably little published work on the ice cover which stops lake surface transport from about December to mid-April every year. Almost all other seasonally ice-bound waters have been the objects of relatively thorough study when compared with the Great Lakes. The Russian Arctic Sea Route came under intense scientific investigation by the Chief Administration of the Northern Sea Route in 1930's, an interest which extended before World War II, to include study of the ice of the Arctic Basin by aerial reconnaissance and from drifting stations (Armstrong, 1952). The first ice observing organization for the Baltic, an area of quasi-inland water most directly comparable to the Great Lakes, was set up in 1909 (Rodhe, 1958). And even the Antarctic sea ice was given its first atlas treatment as far back as 1934 (Hansen, 1934).

Published data on ice formation in some ports and harbors around the Great Lakes have appeared from 1908 onwards, but the record lacks continuity until 1941 when the Detroit office of the U. S. Weather Bureau set up a team of cooperative ice observers around the Great Lakes. Observations were made from mid-February until the ice in the lakes had practically disappeared, and abstracts of the reports were published once a week. Under W. W. Oak, the present Meteorologist-in-charge, data is now collected from the U. S. Coast Guard, from the Meteorological Branch of the Canadian Department of Transport and from various civil airlines on an *ad hoc* basis, as well as from Weather Bureau observers. The purpose of collecting and publishing this material is

to facilitate shipping activities on the Great Lakes at the beginning of each navigation season. There seems to have been no interest in the conditions at the end of the navigation season, possibly because of the dead line laid down for the termination of insurance covering lake shipping on December 1. Beginning of season predictions are more particularly valuable because of the great financial loss sustained when ships are made ready too long before the navigation season opens. It was in answer to this problem that Oak worked out the first ice prediction service for the Great Lakes.

This forecasting service is aimed primarily at predicting the date of opening of various ports. It resulted from a long study to find a statistical correlation between the severity of the winter and the date of port opening. It was found that the average temperature for February at a given port had a significant correlation with the date of opening of that port. If February was cold, then the port opening would be late, and vice versa. Prediction of port opening within ten days was possible by this means. The basic data for this work were the recorded dates of arrival of the first ships of the season at many ports. Although first arrivals would depend to some extent upon the ice conditions, they could also be influenced by other factors such as the degree of economic need, and thus this criterion is not an infallible indicator of the date the port finally cleared of ice. This source of error was recognized, but could not be evaluated. However, the work of the Detroit office of the U. S. Weather Bureau remains the pioneer ice study on the Great Lakes (Oak, 1953, 1955, 1957).

A significant step forward was taken in late 1959 by the Canadian De-

partment of Transport, Meteorological Branch, when they began to fly aerial ice reconnaissance over Lakes Superior, Huron, Erie, and Ontario. These reconnaissances have been carried out each winter since then and have resulted in the first attempt to consider the growth and decay of ice cover on the lakes as a function of the annual temperature cycle (Richards, 1963).

In a qualitative sense, the outline of the normal distribution of ice on the Great Lakes is known. Ice normally first appears in all lakes sometime in December, but may appear as early as November or as late as early January. Because Lake Erie is the shallowest of the lakes, it is the most likely to freeze over completely, but this is a rare occurrence. All the lakes are partially open in almost all winters; how much will vary considerably from year to year. The open area is largely due to the winds which, broadly considered, prevail from the west. The prevalence of this direction, much more than the gentle water flow in the same direction, is responsible for the tendency to build up difficult ice conditions at the eastern ends of Lakes Superior, Erie, and Ontario. The notoriously difficult areas for navigation at the end of each ice season, when the remainder of the lakes may be completely ice free, are Whitefish Bay, a funnel shaped bay at the eastern end of Lake Superior, and at Buffalo at the eastern end of Lake Erie. The pressure ridging of ice (windrowing) throughout the winter in these two areas may increase the thickness of the ice in parts by as much as a factor of five. This greatly increases the longevity of the ice and makes the effective use of icebreakers difficult. The same westerly winds, coupled with a Coriolis effect acting towards the south, tend to made ice conditions more difficult on

the eastern sides of Lake Michigan and Lake Huron than on the western. Three aerial reconnaissance flights over Lake Michigan in March and April, 1963, showed consistently more and older ice on the eastern side of the lake (Heap, 1963). In Lakes Michigan and Huron, more ice is generally found in the northern parts of the lakes. Both lakes have substantial areas of embayed shallow water in Green Bay and Georgian Bay; only in exceptional winters will these fail to freeze over. It is possible that the Coriolis effect mentioned above may also increase ice concentrations on the southern shores of Lakes Superior, Erie, and Ontario.

The break up and disappearance of ice is fairly rapid on all the lakes and usually takes place between early March and mid-April. As indicated above, the general clearance of the lakes may occur considerably before the clearance of ice jams from Whitefish Bay and around Buffalo. These two points may effectively control the starting date for the over-all use of the St. Lawrence Seaway—Great Lakes system.

With this generalized picture of Great Lake ice conditions in mind, the initial problem was to decide whether a collection and analysis of extant ice data would significantly develop knowledge of the ice distribution.

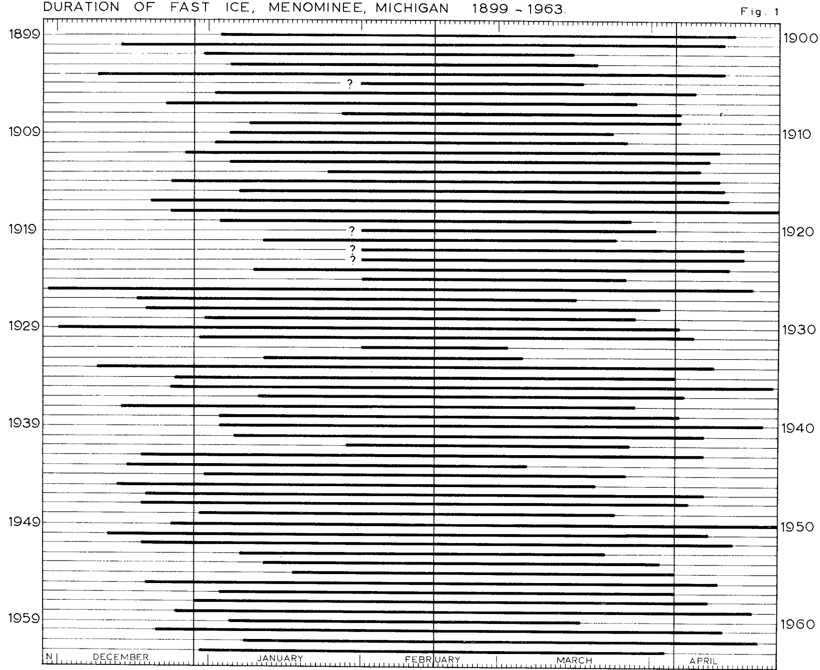
2.1 AVAILABLE DATA

As mentioned above, the most significant corpus of data is that collected by the U. S. Weather Bureau, which reflects conditions in harbors and in areas close to the shore during the period February through April since 1941. This leaves the growth period and mid-lake conditions unknown. Powers et al. (1959), in their exhaustive study of hydro-meteorological data sources for the Great

Lakes, mention but one shore station for which ice data are available for the whole season. This is a list of freeze up and break up dates at Menominee, Michigan, since 1880. For mid-lake material, sources are equally lacking apart from the Canadian aerial reconnaissances. Other possible sources are the U. S. Coast Guard and Commercial shipping. The writer held discussions with the Coast Guard and with the Lake Carriers' Association as to the amount of ice data which might result from analysis of Coast Guard and commercial shipping log books. Since nobody knows now which ships met ice and which did not, it would be necessary to plot all available ships tracks in November-December and April-May. Two points arose from these discussions: (1) Very few ships are out late enough or early enough in the navigation season to encounter ice. Their operations are specifically planned to exclude, as far as possible, the chance of meeting ice. Therefore, the plotting of hundreds of ship tracks would show very little about the presence and position of ice. The analysis of this data might have helped to define the period in which ice was observed to be absent, but since the period of insurance coverage for shipping on the lakes was calculated to exclude ice hazard, analysis to produce data on the absence of ice would only duplicate what is already known. (2) Ships on the lakes do not usually record their positions frequently in their deck logbooks, therefore, plotting of the position where ice was met would be substantially by guesswork.

It was estimated that the analysis of this material by one person would take between one and two years. The useful return for the time and effort expended would be very small.

DURATION OF FAST ICE, MENOMINEE, MICHIGAN 1899 - 1963.



Mean date of freeze up
Standard deviation 13 days

Median date of fast ice duration
Average duration of fast ice: 98 days
Stan. dev. 21 days

Mean date of break up
Stan. dev. 13 days

Fig. 1

2.2 METHODS OF ICE DISTRIBUTION ANALYSIS

The distribution of a dominantly space variable quantity (e.g., human population density), where a representation of the distribution at an instant in time has significance over a lengthy time span, can be adequately mapped by the use of isopleths. But for mapping of a distribution which is as equally time variable as space variable, the isopleth method is inadequate because of the necessary use of averages which may be a misleading representation of the actual conditions. For instance, in Green Bay, it appears that the waters are normally covered with fast ice (10/10ths cover) or are open, the intervening periods of pack ice being short lived. The data for Menominee (Figure 1) show that on April 6 the average ice concentration is about 6/10ths. In fact, these waters, between 1899 and 1963, have been fast in 35 years on this date and open, or nearly so, in 27 years. This sort of data reduction by averaging is clearly misleading. To overcome this problem Armstrong (1958) applied to mapping ice concentration the method of presenting distributions by located sector diagrams. This method allows one to show the number of observations in each category of ice concentration as a proportion of the total number of observations. The data for Menominee on April 6 would appear as in Figure 2.

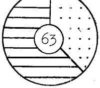
Fast Ice  Open Water

Figure 2

This gives the information that on April 6 the area has been observed in 63 years (figure in center circle), in 27 years open water was observed, and in 36 years fast ice was observed. On April 17 the sector, or frequency, diagram would appear as in Figure 3, which shows that there has been a reduction in the chances of meeting fast ice from 36 in 63 to 11 in 63.

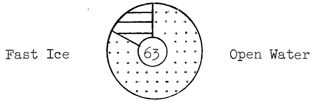


Figure 3

This method gives a clear picture of how ice conditions vary with the time of year.

This method has been used by Armstrong (1958) for mapping sea ice in the Russian Arctic, by Swithinbank (1960) in the Canadian Arctic, and by the present writer in the Antarctic (Heap, 1963b). If this method could have been used for the analysis of Great Lakes ice distribution, it would have been a significant advance, especially as the data are presented in a fashion suitable for detailed consideration of the relationships of ice distribution and climate. It is unfortunate that the data available are insufficient for this type of reduction.

It is clear that the two frequency diagrams above, because of the large number of observations involved (63), are fairly reliable guides to future ice conditions on those days. However, the writer's work on Antarctic ice suggested that not only did the reliability for prediction purposes differ according to the total number of observations but also according to the real

average ice concentration. It was found that if the real average concentration was 5/10ths, then at least 16 observations were necessary to ensure that two-thirds of the observations lay within $\pm 10\%$ of the mean. If the real average concentration was nearly fast ice or nearly open water, then about 8 observations were necessary to fulfill the same conditions. (These statements assume a frequency distribution of ice concentrations approximating to the Normal Curve with possible positive or negative skewness; they do not take into account bimodal frequency distributions of ice concentration.)

Surveying the data available for such a study in the Great Lakes, it was realized that the number of areas in which there would be the necessary 8-16 observations to ensure reasonable reliability would be very few. To sum up, it was evident that the available data would not produce any significant increase in our knowledge of ice distribution on the Great Lakes. Having come to this conclusion, it was felt that the most productive line of enquiry would be a more pragmatic approach. The aim was to formulate a program to study how ice is distributed and how its distribution changes with time as a result of meteorological factors. The form of such a program as discussed in the next section.

3. PROBLEMS AND METHODS OF FUTURE RESEARCH

In a sense, even if the analysis of past observations had been possible and useful, it would have been only a half-way stage towards the primary practical aim of most ice distribution research: the ability to forecast ice formation, movement, and decay. Any program of research on lake ice distribution, which aims to take advantage of the great post World War II advances in ice prediction techniques, must encompass a detailed analysis of the changes in the pattern of ice distribution which can be directly related to the causal meteorological factors.

As a preliminary step in such an enquiry, it seemed best to restrict the work to one lake since the lessons learned from intensive study of one could be applied to others. The choice of Lake Michigan was influenced by the fact that it was not at present being studied, while the Canadians are working on the other four, and by the fact that the Great Lakes Research Division of The University of Michigan is concentrating its attention on this lake.

In the fall of 1962 it was decided to set up a small team of observers around Lake Michigan which would observe the ice from its first appearance to its final departure. Observers were found at Mackinac Island, Mackinac Bridge, Seul Choix Pointe Light Station, Escanaba, Milwaukee, Chicago, and Ludington. Each observer was asked to complete a column of questions on a pro forma sheet (Figure 4) by checking items appropriate to the day's observation. The form was designed to incorporate one or two internal checks on the observers' answers. As far as is known, these observations are the most complete set of

UNIVERSITY OF MICHIGAN ICE OBSERVING PROGRAM, 1962-63, LAKE MICHIGAN

WEEK ______________________ to ______________________
Month Day Month Day

STATION ______________________ OBSERVER ______________________

HEIGHT OF OBSERVATION POINT ______________________

	SAT	SUN	MON	TUE	WED	THU	FRI
DURING PREVIOUS 24 HOURS							
1. Ice is or has been present							
2. There has been no ice							
DURING PREVIOUS 24 HOURS THE ICE SITUATION HAS:							
3. Changed							
4. Not changed							
DURING PREVIOUS 24 HOURS ICE HAS:							
5. Formed by freezing							
6. Consolidated							
7. Drifted in							
8. Melted							
9. Broken up							
10. Drifted out							
11. Windrowed							
FAST ICE IS:							
12. Absent							
13. Present							
14. Width*	y m	y m	y m	y m	y m	y m	y m
15. To horizon							
Thickness	xxx	xxx	xxx	xxx	xxx	xxx	xxx
16. Measured (Inches)							
17. Estimated (Inches)							
DRIFT ICE IS:							
18. Absent							
19. Present							
20. Width*	y m	y m	y m	y m	y m	y m	y m
21. To horizon							
Thickness	xxx	xxx	xxx	xxx	xxx	xxx	xxx
22. Measured (Inches)							
23. Estimated (Inches)							
Concentration	xxx	xxx	xxx	xxx	xxx	xxx	xxx
24. less than 1/10th							
25. 1/10th-4/10ths							
26. 5/10ths-7/10ths							
27. 8/10ths-9/10ths							
28. 10/10ths							
29. Not estimated							

*y = yards; m = miles
Strike out which does not apply.

observations available for any points in the Great Lakes at any time. The program was entirely satisfactory within its primary limitation of being unable to indicate position accurately. To overcome this limitation it is proposed next year to use mapped observations.

When the writer returned, in February 1963, from 5 months field work in the Antarctic, the opportunity was taken to observe the ice of Lake Michigan at first hand. In early March, 1963, a car journey around the lake was made to visit the ice observers and to see whatever could be seen of the ice. In early April a cruise was made on the U. S. Coast Guard icebreaker MACKINAW from Cheboygan, Michigan, through the Straits of Mackinac to Green Bay. Much fast ice was broken both in the Straits and in Green Bay. This was in a state of decay which showed up its internal structure to advantage. These two journeys emphasized the need for study of ice as a mobile three-dimensional distribution. For this reason the research program which is outlined below is aimed at observing the distribution of ice, its growth and decay, and the way pack ice moves in the lake. In writing up the program as a research proposal to the National Science Foundation and the Office of Naval Research, it has been necessary to pay close attention to what is practically possible as well as to what would be theoretically advantageous. The practical aspects are largely controlled by the private or governmental agencies who can be urged into cooperation with the program.

3.1 OBSERVATIONS

In order to obtain estimates of ice area in Lake Michigan, it is necessary to arrange an extensive network of observing points on the lake shore and

to have frequent observations from the air. In order to convert this areal information into quantitative estimates of the mass of ice present, field work must be planned to get data on the thickness of ice. And lastly, in order to understand what has caused ice distribution to change, attention must be paid to the characteristics of ice drift in relation to wind.

3.1.1 Lake Shore Observations

As mentioned above, it is planned that shore observations should be mapped rather than depend upon the written word. The observations envisaged are similar to those successfully introduced by the writer to the Falkland Islands Dependencies Survey (now British Antarctic Survey) in 1957. Observations will be made each day throughout the ice season and will be recorded on small charts prepared and distributed by the writer. On them will be shown ice concentration, thickness, and pressure phenomena. On Friday of each week the preceding week's charts will be mailed to the writer's office where information on ice coverage will be abstracted and sent to the Coast Guard, the U. S. Lake Survey and to the Weather Bureau. From February on these abstracts will be used by the Weather Bureau in their weekly published ice summaries.

The 9th District of the U. S. Coast Guard has kindly agreed to make available observers at 23 Coast Guard stations and lighthouses around the lake to implement this program of shore observation.

3.1.2 Aerial Observation

In the winter of 1962-63, with observers trained by the U. S. Hydrographic Office, the U. S. Lake Survey initiated a program of aerial observation of ice

over the Great Lakes in complement to the activities of the Canadian Department of Transport. The Lake Survey expects that Lake Michigan will be observed about once every two weeks. This observing frequency is similar to that used by the Canadians, the U. S. Hydrographic Office and the Russians to trace ice development in Arctic waters, and should be sufficient to trace the major changes in the ice cover of the lake. The Lake Survey plans to install cameras in its aircraft, and the resulting photographs, together with the manual observer plots, will be made available to the writer. Permission has been given by the Lake Survey for the writer to fly on reconnaissance flights over Lake Michigan.

The Reconnaissance Section of the Michigan Air National Guard has also been approached, and has agreed to cooperate with the program subject to the availability of aircraft at the time. It is proposed to establish a 7-10-day period of intensive photo reconnaissance of the lake in January or early February 1964. The resulting daily photogrammetric charts of ice coverage should be valuable in analyzing ice movement on the lake.

3.2.3 Ice Thickness Studies

The nature of the problem of acquiring data on ice thickness depends on whether the ice to be studied is fast to the shore or is drifting in the lake.

The only perennial extensive areas of fast ice development in Lake Michigan are those in the northern parts of the lake, in Grand Traverse Bay, Green Bay and in parts of the Straits of Mackinac. Minor areas of fast ice occur in most harbors and along protected shores around the entire lake.

At least two ice thickness surveys will be made in Grand Traverse Bay and

Green Bay by using ice drilling techniques, still the cheapest and most accurate way of measuring ice thickness. Each hole takes about 2-3 minutes to drill and measure. The first survey will be made when the ice is thick enough to carry the weight of a small motor toboggan, and the second near the time of maximum thickness. In Grand Traverse Bay, which has some deep water (95 fathoms), a number of crossings will be made, 2 miles apart, of the main Bay and the East Arm; measurements will be made every mile or less if required by the degree of variation discovered. Each drill hole will be marked with a small flagged bamboo in the hope that the majority of them will not be tampered with, and most of the measuring stations can be closely reoccupied later in the season. It is also planned that the bamboos will be used as snow accumulation markers. The position of each hole will be mapped by sextant bearing on known points.

Green Bay, the maximum depth of which is only 22 fathoms, will provide contrasting conditions to Grand Traverse Bay. The same methods will be employed, except the spacing of crossings will be increased to 5 miles. It is hoped that two ice fishermen can be recruited to measure the ice thickness in both bays every week at a few representative points. The two main surveys will tell whether the chosen sites are representative and also where measurements should be made in future years to obtain the most representative samples.

Extensive measurements of ice thickness may be made elsewhere, but throughout this phase of the research the time and place of measurement will depend upon the overriding factor of the observers' safety.

The fast ice around the remainder of the lake, along the smooth shorelines from Sleeping Bear Point, through Chicago to Sturgeon Bay Canal, is normally restricted to a fringe of grounded windrows. Pack ice sometimes lies beyond this fringe and may, from time to time, consolidate and become fast for a while. Around this part of the lake, therefore, it is difficult to get good data on the rate of growth of undisturbed ice. It is not expected that a satisfactory measure of the ice mass involved in this fast ice fringe will be arrived at the first year, but it is planned to make cross-sectional diagrams of the ice thickness between the shoreline and the fast ice edge. It may be possible by this means to throw further light on the genesis and development of fast ice as outlined by Zumberge and Wilson (1954).

Measuring the thickness of drifting ice in the lake is probably the most difficult problem to solve without great expenditure. The Coast Guard has suggested that if measurements can be made without interfering with authorized operations of vessels, there is a possibility of boarding their vessels for this purpose. It may also be possible to obtain such information from fishing boats and estimates from car ferries in certain areas. At the moment, however, there seems to be no sure means of solving this problem without an expensive shipboard program. In the future a multi-purpose program on the drifting ice might justify the chartering of a ship, but at present the problem is best tackled on an ad hoc basis.

The direct measurement of ice thickness by a sampling technique involved in drilling holes through the ice is only a partial solution to the problems of measuring ice growth. As has been pointed out above, the technique is not

usable where the ice is thin as in the first stages of development or out in the mid-lake ice, nor can it be of very widespread application because of the time necessarily involved. It is important, then, to see if a means of remote sensing of ice thickness can be developed which could be installed in an air-craft. Recent work in the Arctic and the Gulf of St. Lawrence has tentatively shown that infrared scanning gives some measure of relative differences in ice thickness where the ice is up to 2 feet thick with only a light snow coverage. By this means it is possible to pick out areas of relative weakness in the ice such as a crack or recently frozen lead which are not visible to the eye or pan-chromatic photography. The problem is to develop infrared, or perhaps some other microwave scanning technique to the point where it will give an absolute measure of ice thickness. It is hoped that the program of direct ice thickness measurement to be carried out in Green Bay or Grand Traverse Bay may provide suitable ground control for testing remote sensing techniques. Plans along these lines are being formulated at present in the University's Special Ap-plications Group of the Infrared Laboratory.

3.1.4 Ice Drift

No work has been done on the direction and speed of drift of ice in any of the Great Lakes. Much work has been done on this problem in the Arctic using data from drifting ice islands (Reed and Campbell, 1960). It is be-lieved that since Lake Michigan is vertically isothermal during the winter (Church, 1942), there are almost no gradient currents in the lake at that season. Since one of the greatest sources of error in the Arctic work has been the unknown quantity of the gradient currents, ice drift observations in

Lake Michigan might serve not only practical but theoretical ends.

Unfortunately, it would be even less comfortable to drift on the ice, in person, across Lake Michigan than across the Arctic Ocean (the ice might melt half-way across), so the problem is one of marking individual floes in some way and subsequently tracking their movement. The simplest method is to freeze in a number of flagged markers either in drift ice, from a ship, or in fast ice considered likely to drift, from the shore. Each marker would be numbered and would carry instructions for any finder to report the date and position of finding. This would, in effect, be using the drift bottle principle and could be accompanied by some publicity around the lake to facilitate possible finding and reporting. This method does, however, have all the uncertainty inherent in current measurement with drift bottles.

While on the MACKINAW in April, 1963, the writer dyed an area of ice 10 feet square to see if this method of marking a floe was readily visible from the air. Although the method had the advantage of not affecting the drift characteristics of the ice, the mark was found to be easily visible only from almost directly above. From an oblique angle of less than about 30° to the ice the mark was hardly visible. It was also found that during the insolation conditions of early April the dye rapidly melted its way into the ice and almost disappeared within 48 hours It is planned to make further experiments with this dye (Rhodamine B) in January, 1964, to see if it lasts longer at that time of year. There is, however, always the risk that it will be obscured by new snow. It is also hoped that other methods may be tried such as the tracking of a marker light by theodolite or the use of small D/F radio beacons.

Most of this work is essentially experimental in evaluating methods of marking and tracking ice. But it is hoped that some valuable data on the relationship of ice drift to wind speed and direction will materialize.

3.2 ASSEMBLY AND REDUCTION OF DATA

During the first winter attention will be devoted entirely to the collection of adequate data on the ice situation as it develops. As information arrives in the writer's office, from shore stations, aerial observations and other sources, it will be mapped on a basic scale of 1:500,000. Information will be mapped on a weekly basis or more frequently if necessary. Special maps will be drawn to show the differences between each successive pair of weekly maps. Not only will this be necessary in later analysis of ice distribution and the weather, but it will help to highlight areas where information is lacking as the winter progresses.

In areas of more intensive study such as Grand Traverse Bay and Green Bay, data will be mapped at larger scales. The mapping and analysis of results from infrared scanner reconnaissances will be in the hands of the Infrared Laboratory. The method of using aerial photography depends upon the amount of coverage and the scale of the photography If photographic coverage of an area of the lake is completed on a number of successive days, the aim would be to compile photo mosaics of the ice area and to reduce these to manageable proportions by producing photographs of the mosaics at a scale of approximately 1:100,000.

When the season is over, all the mapped information will be analyzed by planimetry to show the horizontal growth and recession in the area of ice.

All available thickness data will then be used to arrive at measures of vertical ice growth and decay in various areas during the winter. From this will be calculated the major changes with time in the mass of ice present.

The next step will be to relate ice formation, growth and decay with the pre-winter, winter and spring temperatures (Billelo, 1961; Rodhe, 1952, 1955). The last stage will be to consider the relationship of ice drift with wind regime. Depending on the type of results obtained from the ice drift experiments it is hoped to deduce some empirical relationships on the drift speed and the time lag between a change in the wind direction and the time when the ice is drifting in full response to the new direction.

After the first phase of the work is completed, the second will start with the construction of maps of normal ice growth and decay, using the relationships worked out previously and in conjunction with the well documented climatology of the lake region. Coupling these parameters with long range forecasts (U. S. Weather Bureau's Extended Section's 5-day and 30-day forecasts), predictions will be made of the first appearance of ice and of its subsequent growth and decay. The predictions will then be verified in the field, using the observation system described for the first winter's work. This will involve, as a second check, consideration of the progressive temperature anomaly (departure from normal) and whether this explains anomalous ice growth (Wittman, 1958). The exact method of forecasting ice drift will depend on the results of the first winter's work. It may be possible to apply Wittman's suggestions, at least as a beginning.

Experience during the first winter may suggest considerable modifications in the above outline. More detailed intensive field work will be indicated in

all probability. However, it is hoped that some of the large-scale field work, such as ice thickness measurements, may be handed on to volunteer observers, at least in part.

The initiation of the program proposed above will, of course, depend upon funds being made available. At the time of writing these remain uncertain.

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